SPECIES: Linaria spp.

Choose from the following categories of information.

INTRODUCTORY

SPECIES: Linaria spp.

Dalmatian toadflax flowers
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Dalmatian toadflax infestation
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AUTHORSHIP AND CITATION:
Zouhar, Kris. 2003. Linaria spp. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2007, September 24].

FEIS ABBREVIATION:
LINSPP
LINDAL
LINVUL

SYNONYMS:
Linaria genistifolia (L.) P. Mill ssp. *dalmatica* (L.) Maire & Petitm. [42,48,66,117,118]
=*L. dalmatica* (L.) P. Mill. [14,28,31,49,56,62,113,119]

NRCS PLANT CODE [110]:
LINAR
LIDA
LIVU2

COMMON NAMES:
toadflax
Dalmatian toadflax
dalmatian toadflax
yellow toadflax
butter-and-eggs
common toadflax

TAXONOMY:
The currently accepted genus name for toadflax is *Linaria* P. Mill (Scrophulariaceae) [14,28,31,47,56,62,113,119]. This report summarizes information on 2 species of toadflax:

Linaria dalmatica (L.) P. Mill. [14,28,31,43,47,49,56,62,113,119] Dalmatian toadflax
Linaria vulgaris P. Mill. [14,19,28,31,42,43,47,48,56,62,66,79,104,113,117,118,119,122] yellow toadflax

For the purposes of this review, the common name toadflax will be used when discussing characteristics common to both species, or when it is unclear which of the species was studied. When referring to individual species, the common names listed above will be used to represent the respective scientific name.

A review by Saner and others [95] reports that hybrids between yellow toadflax and Dalmatian toadflax can be produced in the laboratory, and therefore occurrence of this hybrid in the field cannot be excluded. Hybrids between yellow toadflax and striped toadflax (*Linaria repens*) commonly occur. This hybrid was described as *Linaria* x *sepium*
J. G. Allman from the British Islands in 1843 and was discovered near St. John's, Newfoundland, in the early 1900s ([95] and references therein).

LIFE FORM:
Forb

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
Dalmatian toadflax is classified as a noxious weed or weed seed in 11 states in the U.S. and 3 Canadian provinces. Yellow toadflax is classified as a noxious weed or weed seed in 9 states in the U.S. and 4 Canadian provinces [111]. See the Invaders or Plants databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: Linaria spp.

- BLM PHYSIOGRAPHIC REGIONS
- KUCHLER PLANT ASSOCIATIONS
- SAF COVER TYPES
- SRM (RANGELAND) COVER TYPES
- HABITAT TYPES AND PLANT COMMUNITIES

GENERAL DISTRIBUTION:
The following discussion of the origin, introduction and distribution of Dalmatian toadflax and yellow toadflax is based on several review articles [11,57,95,114], unless other sources are cited.

Dalmatian toadflax is a native of the Mediterranean region from Yugoslavia to Iran [88]. Yellow toadflax is native to the steppes of southeastern Europe and southwestern Asia [95]. Both species have been cultivated as ornamentals for centuries and are widely distributed throughout the world [1,95,114].

It has been suggested that Dalmatian toadflax was introduced to North America as an ornamental in the late 1800s; however, the earliest authentic specimen was collected in California in 1920 [1,114]. Yellow toadflax was introduced to New England in the late 1600s as an ornamental and medicinal plant and continues to be sold in nurseries and seed catalogs. For example, Gutknecht [35] lists "*Linaria vulgaris* (common toadflax or butter-and-eggs)" as a plant that is well suited for xeriscaping. The spread of toadflax was facilitated by its use as an ornamental, medicinal, magical, and dye plant, although accidental introduction and distribution along roads and railway corridors, or in crop seed, baled hay, ship ballast, and clothing likely increased its spread [57,95].

Toadflax occurs throughout the continental U.S. and in almost every Canadian province [47,110]. Yellow toadflax is most common in northeastern North America, and localized in other parts of the continent, particularly the western Canadian provinces [57]. The northern limits of yellow toadflax's North American range are approximately 55° N to 65° N [95]. The latitudinal range of Dalmatian toadflax in North America is from about 33° N to about 56° N, as compared to a range of about 35° N to 47° N in Eurasia [1]. Dalmatian toadflax is most common in western North America, especially in California, Oregon, Washington, Idaho, Montana, Wyoming, Alberta, and British Columbia [11,57,77], and it is spreading in the Southwest. For example, it is estimated to have invaded 200,000 acres (80,000 ha) on the Coconino National Forest in northern Arizona as of 2001 [76].

Toadflax is most commonly found in cultivated fields, roadsides, railways, "waste areas", clearcuts, overgrazed pastures and rangeland, and in plant communities that are typically open or disturbed [6,57]. Neither species occurs as frequently in intact wildlands and natural areas.

The following lists include some ecosystems, habitats, and forest and range cover types in which toadflax is known or thought to be invasive, as well as several that may be invaded by toadflax following disturbances in which vegetation is killed and/or removed (e.g. cultivation, logging, fire, grazing, herbicide application, flooding). These lists are speculative and not exhaustive. More information is needed regarding incidents and examples of particular ecosystems and plant communities where toadflax is invasive.

ECOSYSTEMS [27]:
FRES10 White-red-jack pine
FRES11 Spruce-fir
FRES15 Oak-hickory
FRES17 Elm-ash-cottonwood
FRES18 Maple-beech-birch
FRES19 Aspen-birch
FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine

FRES23 Fir-spruce
FRES25 Larch
FRES26 Lodgepole pine
FRES28 Western hardwoods
FRES29 Sagebrush
FRES30 Desert shrub
FRES33 Southwestern shrubsteppe
FRES34 Chaparral-mountain shrub
FRES35 Pinyon-juniper
FRES36 Mountain grasslands
FRES37 Mountain meadows
FRES38 Plains grasslands
FRES39 Prairie
FRES40 Desert grasslands
FRES42 Annual grasslands

STATES/PROVINCES: (key to state/province abbreviations)

Dalmatian toadflax:

UNITED STATES

AZ	CA	CO	CT	ID	IL	IN	IA	KS	ME
MA	MI	MN	MT	NE	NV	NH	NJ	NM	NY
ND	OH	OK	OR	PA	SD	UT	VT	WA	WI
WY									

CANADA

AB	BC	MB	NB	NS	ON	PE	PQ	SK

MEXICO

yellow toadflax:

UNITED STATES

AL	AK	AZ	AR	CA	CO	CT	DE	FL	GA
ID	IL	IN	IA	KS	KY	LA	ME	MD	MA
MI	MN	MS	MO	MT	NE	NV	NH	NJ	NM
NY	NC	ND	OH	OK	OR	PA	RI	SC	SD
TN	TX	UT	VT	VA	WA	WV	WI	WY	DC

CANADA

AB	BC	MB	NB	NT	NS	ON	PE	PQ	SK
YK									

MEXICO

BLM PHYSIOGRAPHIC REGIONS [9]:
1 Northern Pacific Border
2 Cascade Mountains
3 Southern Pacific Border
4 Sierra Mountains
5 Columbia Plateau
6 Upper Basin and Range
7 Lower Basin and Range
8 Northern Rocky Mountains
9 Middle Rocky Mountains
10 Wyoming Basin
11 Southern Rocky Mountains
12 Colorado Plateau
13 Rocky Mountain Piedmont
14 Great Plains
15 Black Hills Uplift
16 Upper Missouri Basin and Broken Lands

KUCHLER [53] PLANT ASSOCIATIONS:
K011 Western ponderosa forest
K012 Douglas-fir forest
K016 Eastern ponderosa forest
K017 Black Hills pine forest
K018 Pine-Douglas-fir forest
K019 Arizona pine forest
K022 Great Basin pine forest
K023 Juniper-pinyon woodland
K024 Juniper steppe woodland
K026 Oregon oakwoods
K030 California oakwoods
K031 Oak-juniper woodland
K032 Transition between K031 and K037
K033 Chaparral
K034 Montane chaparral
K035 Coastal sagebrush
K036 Mosaic of K030 and K035
K037 Mountain-mahogany-oak scrub
K038 Great Basin sagebrush
K047 Fescue-oatgrass
K048 California steppe
K050 Fescue-wheatgrass
K051 Wheatgrass-bluegrass
K053 Grama-galleta steppe
K054 Grama-tobosa prairie
K055 Sagebrush steppe
K056 Wheatgrass-needlegrass shrubsteppe
K057 Galleta-threeawn shrubsteppe
K058 Grama-tobosa shrubsteppe
K063 Foothills prairie
K064 Grama-needlegrass-wheatgrass

K065 Grama-buffalo grass
K066 Wheatgrass-needlegrass
K067 Wheatgrass-bluestem-needlegrass
K068 Wheatgrass-grama-buffalo grass
K069 Bluestem-grama prairie
K070 Sandsage-bluestem prairie
K074 Bluestem prairie
K075 Nebraska Sandhills prairie
K081 Oak savanna
K082 Mosaic of K074 and K100
K093 Great Lakes spruce-fir forest
K094 Conifer bog
K095 Great Lakes pine forest
K098 Northern floodplain forest
K100 Oak-hickory forest
K101 Elm-ash forest
K103 Mixed mesophytic forest
K106 Northern hardwoods

SAF COVER TYPES [22]:
1 Jack pine
14 Northern pin oak
16 Aspen
38 Tamarack
40 Post oak-blackjack oak
42 Bur oak
43 Bear oak
52 White oak-black oak-northern red oak
63 Cottonwood
95 Black willow
109 Hawthorn
110 Black oak
203 Balsam poplar
209 Bristlecone pine
210 Interior Douglas-fir
212 Western larch
215 Western white pine
217 Aspen
218 Lodgepole pine
219 Limber pine
220 Rocky Mountain juniper
222 Black cottonwood-willow
233 Oregon white oak
235 Cottonwood-willow
236 Bur oak
237 Interior ponderosa pine
238 Western juniper
239 Pinyon-juniper
240 Arizona cypress
241 Western live oak
245 Pacific ponderosa pine
246 California black oak

247 Jeffrey pine
248 Knobcone pine
249 Canyon live oak
250 Blue oak-foothills pine

SRM (RANGELAND) COVER TYPES [99]:
101 Bluebunch wheatgrass
102 Idaho fescue
103 Green fescue
104 Antelope bitterbrush-bluebunch wheatgrass
105 Antelope bitterbrush-Idaho fescue
106 Bluegrass scabland
107 Western juniper/big sagebrush/bluebunch wheatgrass
109 Ponderosa pine shrubland
110 Ponderosa pine-grassland
201 Blue oak woodland
203 Riparian woodland
205 Coastal sage shrub
206 Chamise chaparral
207 Scrub oak mixed chaparral
208 Ceanothus mixed chaparral
209 Montane shrubland
210 Bitterbrush
214 Coastal prairie
215 Valley grassland
216 Montane meadows
301 Bluebunch wheatgrass-blue grama
302 Bluebunch wheatgrass-Sandberg bluegrass
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
309 Idaho fescue-western wheatgrass
310 Needle-and-thread-blue grama
311 Rough fescue-bluebunch wheatgrass
312 Rough fescue-Idaho fescue
314 Big sagebrush-bluebunch wheatgrass
315 Big sagebrush-Idaho fescue
316 Big sagebrush-rough fescue
317 Bitterbrush-bluebunch wheatgrass
318 Bitterbrush-Idaho fescue
319 Bitterbrush-rough fescue
320 Black sagebrush-bluebunch wheatgrass
321 Black sagebrush-Idaho fescue
322 Curlleaf mountain-mahogany-bluebunch wheatgrass
323 Shrubby cinquefoil-rough fescue
324 Threetip sagebrush-Idaho fescue
401 Basin big sagebrush
402 Mountain big sagebrush
403 Wyoming big sagebrush
404 Threetip sagebrush

405 Black sagebrush
406 Low sagebrush
407 Stiff sagebrush
408 Other sagebrush types
409 Tall forb
411 Aspen woodland
412 Juniper-pinyon woodland
413 Gambel oak
415 Curlleaf mountain-mahogany
416 True mountain-mahogany
417 Littleleaf mountain-mahogany
418 Bigtooth maple
419 Bittercherry
420 Snowbrush
421 Chokecherry-serviceberry-rose
422 Riparian
502 Grama-galleta
503 Arizona chaparral
504 Juniper-pinyon pine woodland
509 Transition between oak-juniper woodland and mahogany-oak association
601 Bluestem prairie
602 Bluestem-prairie sandreed
603 Prairie sandreed-needlegrass
604 Bluestem-grama prairie
605 Sandsage prairie
606 Wheatgrass-bluestem-needlegrass
607 Wheatgrass-needlegrass
608 Wheatgrass-grama-needlegrass
609 Wheatgrass-grama
610 Wheatgrass
611 Blue grama-buffalo grass
612 Sagebrush-grass
613 Fescue grassland
614 Crested wheatgrass
615 Wheatgrass-saltgrass-grama
722 Sand sagebrush-mixed prairie
733 Juniper-oak
735 Sideoats grama-sumac-juniper
801 Savanna
804 Tall fescue
805 Riparian

HABITAT TYPES AND PLANT COMMUNITIES:
Toadflax most commonly invades disturbed plant communities typical of cultivated areas, roadsides and other "waste places." It also invades communities with naturally-occurring disturbances or small openings [6,57]. For example, Dalmatian toadflax is said to be highly invasive and competitive in sagebrush (*Artemisia* spp.) ecosystems [77], and is often invasive in open ponderosa pine (*Pinus ponderosa*), bunchgrass, and riparian communities.

Dalmatian toadflax may displace natives in shrub-steppe communities in Washington [81]. It was found in trace amounts in ponderosa pine-bluebunch wheatgrass (*Pseudoroegneria spicata*) and ponderosa pine-Thurber needlegrass (*Achnatherum thurberianum*) habitat types in Washington and Idaho in the late

1960s [16]. In Oregon, Dalmatian toadflax is found in bluebunch wheatgrass-Sandberg bluegrass (*Poa secunda*) and Idaho fescue (*Festuca idahoensis*)-bluebunch wheatgrass communities, and on gravel bars in riparian communities [81].

In Montana, Dalmatian toadflax forms large colonies in dry mountain grasslands of valleys and foothills [56], on sites formerly dominated by native prairie species such as Idaho fescue and bluebunch wheatgrass. These sites are now dominated by Dalmatian toadflax, leafy spurge (*Euphorbia esula*), spotted knapweed (*Centaurea maculosa*), cheatgrass (*Bromus tectorum*) [61], and sulphur cinquefoil (*Potentilla recta*) (personal observation). In Glacier National Park, Montana, Dalmatian toadflax occurs in rough fescue (*Festuca altaica*)-Idaho fescue habitat types along roadsides [107].

In Yellowstone National Park, Wyoming, Dalmatian toadflax was found at Mammoth Campground in a big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass habitat type. It was not found at campgrounds at higher elevations [2].

Toadflax often occurs in riparian areas in Colorado. It is found, for example, on gravel bars in the south fork of the San Miguel River that are flanked by riparian forests of cottonwood (*Populus* spp.) and spruce (*Picea* spp.) [82]. Along the Yampa River area in Colorado, Dalmatian toadflax spreads in from adjacent upland areas and along the river. It is found in gravel bars, riparian pastures, and open meadows, and may compete with cottonwood seedlings for establishment sites on gravel bars. In Phantom, Colorado, the river and trails are conduits to dispersal of Dalmatian toadflax. It may also invade mountain-mahogany (*Cercocarpus* spp.) shrubland and shortgrass prairie communities adjacent to riparian corridors [81].

In Utah, Dalmatian toadflax is found in oak (*Quercus* spp.), quaking aspen (*Populus tremuloides*), sagebrush, mountain brush, and riparian communities [119].

Dalmatian toadflax is found, though rare, in sandy soils and washes in oak woodland in Fort Bowie National Historic Site in southeastern Arizona [116]. It is also found in northern Arizona in Bebb willow (*Salix bebbiana*) wet meadow, fescue (*Festuca* spp.)-muhly (*Muhlenbergia* spp.) grassland, and mixed conifer understory communities [81].

Less information is available for plant communities in which yellow toadflax is found. It is most common in agricultural areas [95].

Yellow toadflax was found in a jack pine (*Pinus banksiana*)-lichen woodland of the upper boreal forest in northern Quebec, 2 years after wildfire [100]; and was identified in a ponderosa pine/bluebunch wheatgrass community in Montana [83].

In Kentucky, yellow toadflax is found along roadsides with purple crownvetch (*Coronilla varia*) and tall fescue (*Festuca arundinacea*) (used to revegetate the roadsides), along with staghorn sumac (*Rhus typhina*), bluegrass (*Poa* spp.), great ragweed (*Ambrosia trifida*), and goldenrod (*Solidago* spp.) [60].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Linaria spp.

- SEASONAL DEVELOPMENT

GENERAL BOTANICAL CHARACTERISTICS:
The following description of toadflax presents characteristics that may be relevant to fire ecology, and is not meant for identification. Correct identification of toadflax is important if control strategies are planned, because it may be confused with native snapdragons (*Antirrhinum* spp.). Keys for identification are available (e.g. [14,31,43,117,119]).

Dalmatian and yellow toadflax are deep-rooted, short-lived, herbaceous perennials. They reproduce by seed, and can form colonies by means of adventitious buds on roots. Toadflax shoots are tough and somewhat woody near the base, and are produced singly or in clumps of up to 25 stems per crown, spaced along the shallow, lateral roots [1,88,95,114].

Dalmatian toadflax is variable in many characteristics [1]. Stems of Dalmatian toadflax are 16 to 36 inches (40-90 cm) tall or taller, somewhat woody at the base, and the upper portion is frequently branched. Decumbent to weakly ascending stems are produced in the fall [1,88]. Both leaves and stems are waxy. Leaves are usually heart-shaped, 0.8 to 2 inches (2-5 cm) long, 0.4 to 0.6 inch (10-16 mm) wide with clasping bases. Flowers grow in the axils of upper leaves, in loose, elongate, terminal racemes and have a spur that is about as long as the rest of the flower (0.6 to 0.9 inch (14-24 mm)). The fruit is a capsule, 6-7 mm long and 4-8 mm wide, bearing an average of 140 to 250 seeds [87]. Seeds are 1.2-2 mm long with wings [14,28,31,62,119].

Yellow toadflax has a variable habit, depending on environmental factors such as shading, grazing, or soil type, which may be expressed in flower and pollen grain morphology [95]. Yellow toadflax stems are usually 12 to 36 inches (30-90 cm) tall, simple to branched. Yellow toadflax leaves are narrow, linear, 1 to 2 inches (2.5-5 cm) long, 2-6 mm wide, somewhat pointed at both ends, and not clasping. Yellow toadflax flowers occur at first in clusters near the ends of the stems, growing at the bases of upper leaves, and becoming more widely spaced along the stem as the season progresses [57,119]. Yellow toadflax flowers also have a spur that is about as long as the rest to the flower (10-14 mm) [14,28,31,119]. Yellow toadflax fruit is a capsule, 5-12 mm long, bearing a highly variable number of viable seeds [6,12] about 2 mm long with broad wings [14,95].

Mature toadflax plants have extensive, well-developed root systems. Taproots of a mature Dalmatian toadflax plant may reach depths of 4 to 10 feet (1.3-3 m), and lateral roots can extend 12 feet (3.6 m) from the parent plant. Vegetative buds were found as deep as 6 feet (1.8 m) in coarse soil. However, most Dalmatian toadflax plants produced from vegetative buds occur on lateral roots that are found in the upper 2 to 12 inches (5-30 cm) of soil [1,88]. Mature yellow toadflax taproots may grow 3.3 feet (1 m) deep, and lateral roots can be several meters long. Shoots tend to grow from vegetative buds that are around 0.8 to 2 inches (2-5 cm) below the soil surface [95].

These extensive root systems allow toadflax plants to exploit water resources efficiently and provide an effective anchor that prevents grazing animals and cultivation methods from dislodging or destroying plants. Superficial yellow toadflax roots do not overwinter; however, the roots are able to survive freezing to 5 degrees Fahrenheit (-15 °C) after artificial acclimatization to low temperatures [95].

Roots of both Dalmatian toadflax and yellow toadflax are colonized by VAM fungi, probably less so in cultivated soil than in populations established in less disturbed areas [39].

A life span of at least 4 years for individual roots has been reported for yellow toadflax [95], while individual Dalmatian toadflax plants are thought to live an average of 3 to 5 years. Dalmatian toadflax patches can persist for 13 years or more under favorable conditions. Dalmatian toadflax stands sometimes disappear for several years, then re-establish, either from buried seeds, or perhaps from vegetative root buds [88]. In this way a stand may persist indefinitely [57]. The age of toadflax plants may be determined by observing growth rings in the secondary xylem of the main root [18,88].

RAUNKIAER [80] LIFE FORM:
Hemicryptophyte
Geophyte

REGENERATION PROCESSES:
Dalmatian toadflax and yellow toadflax reproduce by seeds and by vegetative buds on roots. New infestations of toadflax usually originate from seed. Established patches of Dalmatian toadflax expand by both seed and vegetative reproduction, while yellow toadflax patches expand primarily by vegetative reproduction.

Breeding system: Both Dalmatian toadflax and yellow toadflax are self-incompatible [6,20,95,114]. However, a review by Saner and others [95] suggests that a small proportion of yellow toadflax seeds can develop without cross-pollination.

Pollination: Dalmatian toadflax and yellow toadflax are both insect pollinated [6,95,114]. Conspicuous yellow flowers with bright orange palates (nectar guides) make toadflax well adapted to insect pollination. Yellow toadflax is pollinated mostly by bumblebees and it is only of minor importance for honeybees [95].

Seed production: Viable seed production in toadflax is variable due to availability of outcross pollen [12], pollinator limitation, predation by insects [6], resource limitations [12], and variable flowering phenology [95].

Robocker [87] studied seed production in Dalmatian toadflax and found that capsules on main stems averaged 250 seeds per capsule while those on branches contained an average of 140 seeds per capsule. He calculated that, with minimal competition and good moisture availability, a Dalmatian toadflax plant with 10 stems could potentially produce 500,000 seeds. A review by Vujnovic and Wein [114] cites a study finding that plants with 12-15 stems produced up to 400,000 seeds.

Studies of yellow toadflax report low seed set and low seed viability. The average number of seeds per capsule ranges between 3 and 47 in North America [6,12] and from 70 to 110 in central Europe. Capsules formed later in the growing season tend to produce more viable seed. Some populations of yellow toadflax may never produce more than 25% viable seed [12]. Average number of seeds produced per yellow toadflax stem may vary from 165 to 5,584. Seed counts on a per plant basis are difficult to compare as the definition of what constitutes an individual is unclear. Mean numbers from 1,500 to 30,000 have been reported ([95] and references therein).

Nadeau and King [69] found that seed production of 210,000 seeds per m^2 within a 0.5 m radius around yellow toadflax parent plants was reduced to 1,410 seeds per m^2 within a 0.5 m radius in the subsequent year when biological control insects were abundant.

Many seed studies fail to differentiate between viable and nonviable seeds. Clements and Cavers [12] observed seasonal differences in number of viable seeds produced by yellow toadflax and attributed these differences to differential seed development in response to variable resource availability.

Seed dispersal:
Toadflax seeds are formed in capsules on the terminal portions of branched stems. The capsules dry over time, crack open and release seeds [69]. Although the seeds are winged, and wind has been considered a major means of seed dispersal for toadflax species [2,87,88], Nadeau and King [69] observed that over 80% of yellow toadflax seeds fell within an 18-inch (50 cm) radius of the parent plant, and "very few" seeds fell more than 5 feet (1.5 m) from the parent plant.

Average seed size is similar for yellow and Dalmatian toadflax. Dalmatian toadflax seeds are slightly heavier [87], and the papery wing surrounding the seeds is less developed on Dalmatian toadflax. This suggests that Dalmatian toadflax seeds probably also fall within short distances of the parent plant. When seeds of either

species fall from upright dried floral stems onto crusted snow, they can be blown by wind across the surface of the snow ([57] and references therein).

A review by Saner and others [95] suggests yellow toadflax seeds may also be dispersed by water, ants, birds, and rodents. Seed dispersal via farm equipment is likely an important mode of dispersal in agricultural areas. Dalmatian toadflax may also be dispersed by cattle, deer and other browsing animals [87,114]. Dalmatian toadflax seeds can remain viable after passing through the gastrointestinal tracts of cattle, and possibly deer [87].

Seed banking: Nadeau and King [69] found that yellow toadflax seeds kept in the dark at 68 degrees Fahrenheit (20 °C) produced few seedlings, suggesting a strong dormancy in yellow toadflax seeds. Dormancy was broken with wet stratification, with maximum germination obtained after 8 weeks of wet stratification [69]. Seed stored at room temperature for 13 years had a germination rate of 67%, at optimum germination temperatures. Under field conditions at Spokane, Washington, researchers estimate Dalmatian toadflax seed longevity at 10 years, with duration of viability dependent on soil and climatic conditions [87].

Results presented by Grieshop and Nowierski [32] suggest Dalmatian toadflax produces enough seeds to exceed potential emergence sites. Therefore, many Dalmatian toadflax seeds may remain ungerminated each year [32]. Because only a portion of toadflax seeds may germinate in any given year, and because seeds can remain viable for several years [87,88], dormant, soil-stored seeds can reinfest a site following control applications or other disturbances that reduce plant competition [57].

Germination:

Toadflax seed viability and germination rates are variable. Factors that may affect toadflax seed viability include resource limitation, seed predators, and pollinator limitation. Germination is affected by temperature, light, seed dormancy and after-ripening.

Nadeau and King [69] found 40 to 51% average seed viability (by tetrazolium chloride test) in yellow toadflax seed collected throughout the season in Alberta. Clements and Cavers [12] found most of the observed seasonal differences in yellow toadflax seed viability in their study were the result of differential seed development in response to variable resource availability. Insect predation can also affect toadflax seed viability. McClay [63] found that seed viability and individual seed weight were seriously reduced on plants attacked by *Brachypterolus pulicarius*, and Nadeau and King [69] observed reduced seed viability in a year when there was heavy predation by *B. pulicarius* and *G. antirrhini* (see Biological control for more information on these biological control insects).

Yellow toadflax seed germination rates vary greatly but are usually low. Clements and Cavers [12] report yellow toadflax germination rates ranging from 13.5% to 65.8%. Remaining seeds are either dormant or nonviable [12]. Some yellow toadflax seeds may germinate immediately, but most seeds remain dormant. Seed dormancies of 8 years have been reported. Yellow toadflax seeds germinate in the top 0.8 to 1.2 inches (2-3 cm) of soil and may also germinate on the soil surface. In most experiments, light appeared to induce germination. Germination rates of 88% were observed following chilling and subsequent exposure to alternating temperatures ([95] and references therein). Wet stratification can also induce germination of yellow toadflax seeds [69].

Germination rates may be as high as 75% for Dalmatian toadflax [57]. Robocker [87] found that Dalmatian toadflax seeds germinated within a narrow temperature range, and that many seeds were carried over from year to year. Seeds germinated if they were not buried deeper than 1 inch (2.5 cm) in clay and loamy sand soil, and 1.2 inches (3 cm) in sandy soil [1,87]. In the field, emergence of Dalmatian toadflax seeds usually occurs from depths less than 5 mm. Newly harvested Dalmatian toadflax seeds are usually dormant. Dormancy declines and germination rates increase with seed age up to 5 to 6 weeks after maturation. Of the Dalmatian toadflax seeds produced during the first 5 weeks of maturation, 67% germinated in October (about 3 months after collection). Low winter temperatures break dormancy [87]. Some Dalmatian toadflax seeds germinate in fall, but most

germinate in spring, with peaks in April and May [57].

Seedling establishment/growth:

Toadflax seedlings are vulnerable to dehydration, competition from other species, and certain control strategies.

Dalmatian toadflax seedlings died following rapid or extreme temperature changes or dehydration in field and greenhouse studies. When Dalmatian toadflax seeds germinate in autumn, seedling survival the next year depends on sufficient spring and early summer precipitation, or a lack of competition from other plants. Dalmatian toadflax seedlings are easily outcompeted by established plants, especially perennial species [87], and also by cheatgrass on fertile soils. Conversely, cheatgrass does not compete well with established Dalmatian toadflax plants [88]. Cultivation or soil disturbance that removes perennial plants may increase Dalmatian toadflax seedling survival [87].

Grieshop and Nowierski [32] found, under the field conditions of their 2-year study, that Dalmatian toadflax populations filled most "safe seedling emergence sites" and seedling recruitment of Dalmatian toadflax was limited more by interspecific resource competition than by seed numbers. Because Dalmatian toadflax can produce enough seeds to exceed potential emergence sites, and because Dalmatian toadflax plants reproduce vegetatively, it appears that individual seedling recruitment in Dalmatian toadflax is more important for establishing new populations than it is for maintaining established populations [32].

Similarly, vegetative reproduction in yellow toadflax is more important than seedling establishment for maintaining populations of yellow toadflax. Yellow toadflax can produce a large number of seeds. However, low viability and strong seed dormancy result in poor yellow toadflax seedling establishment, especially with competition. Once established, yellow toadflax seedlings have a rapid rate of growth and vegetative spread, enabling them to colonize a suitable niche quickly when competitive stresses are low [69].

Yellow toadflax seedlings (genets) can produce daughter shoots (ramets) from vegetative root buds as early as 3 weeks after cotyledon appearance. A single ramet or genet of yellow toadflax would be equally capable of initiating a new yellow toadflax infestation; however, young genets are highly susceptible to control techniques and crop competition in the first 3 weeks of growth, while the larger root system of ramets may resist the effects of control treatments such as mowing and tillage. Tillage operations could readily spread toadflax infestations because of the ability of small portions of underground plant parts to produce new shoots [70]. It has been reported that a yellow toadflax patch with a radius of almost 3.3 feet (1 m) developed from a first-year seedling in 1 growing season, and established patches can increase in diameter an average of 4 feet (1.2 m) per year in Saskatchewan [95].

Roots of Dalmatian toadflax seedlings grow an average of about 2 inches (6 cm) per week, with the uppermost primary branch tending to grow horizontally at depths of 0.8 to 4 inches (2-10 cm) [88].

Asexual regeneration:

Toadflax can reproduce vegetatively by the formation of adventitious shoots from both the tap and lateral roots, and from root fragments [88,95]; and can sprout from buds in the axils of vestigial leaves at the bases of floral shoots when shoots are removed [89].

Vegetative reproduction is possible from toadflax root fragments as short as 0.4 inch (1 cm) and is common from fragments of 4 inches (10 cm). In Alberta, a 4-inch-long (10 cm) piece of yellow toadflax root with a 4-inch-high (10 cm) shoot produced a patch 3.3 to 6.6 feet (1-2 m) in diameter in one growing season, and produced an average of 75 or 694 shoots, in barley (*Hordeum* spp.) or on fallow land, respectively. Seedlings appear to be important in initiating new yellow toadflax infestations in nonarable lands, while in arable land, root pieces can cling to farm implements, easily initiating new infestations [68].

A review by Saner and others [95] describes the mature root system of yellow toadflax as having "long roots"

that are perennial and bear buds, and "short roots" that are annual. The rate of bud formation in yellow toadflax roots is highly variable, stimulated by exposure to light, and somewhat inhibited by soil disturbance. Vegetative reproduction from yellow toadflax root buds can begin as early as 2 to 3 weeks after germination, and an extensive root system may develop within a single growing season. Yellow toadflax plants typically produce 90 to 100 secondary shoots from the root system in the 1st year and 200 to 250 shoots by the 2nd year ([95] and references therein).

Established infestations of yellow toadflax appear to expand mainly by vegetative reproduction rather than by seed. Since the majority of yellow toadflax seed is dispersed within 6.6 feet (2 m) of the parent plant, and vegetative spread is common, this species is likely to spread by increasing individual patch size [69]. Distribution of toadflax patches may be influenced by competition. Nadeau and others [68] observed small clumps of shoots consistently appeared in a ring around the original yellow toadflax stand on fallow land, whereas in a barley crop clumping was reduced and shoots did not form a ring. Yellow toadflax produced 20 to 75 shoots in a 1.3- to 3.3-foot-diameter (0.4-1 m) patch when growing with barley, as compared with 197-694 stems in 3.3- to 6.6-foot-diameter (1-2 m) patch growing on fallow land in Alberta [68].

In studies in Pullman, Washington, persistence of Dalmatian toadflax was dependent on both yearly extension of lateral roots and establishment of new seedlings [86,89].

SITE CHARACTERISTICS:
Lajeunesse [57] suggests that a high degree of genetic variation in toadflax allows it to adapt to a wide variety of conditions. These species evolved in areas where much of the land is cultivated, and are adapted to the periodic disturbances of agriculture [57]. In North America, they are most commonly found on disturbed sites such as roadsides, fencelines, areas near dwellings, vacant lots, cemeteries, gravel pits, croplands, clearcuts, pastures, waste areas, and other disturbed sites where removal of vegetation allows toadflax seedlings to establish [11,57,95]. Similarly, typical yellow toadflax habitats in Europe include vineyards, woodland clearings, and clearcuts. In Europe, large populations of yellow toadflax were observed on fields where competing vegetation was depressed by grazing or fire, and on some sites (e.g. between trees in orchards or in train yards) that had been subject to regular application of broad-action herbicides [95]. Dalmatian toadflax invasion is also encouraged by repeated grazing and herbicide applications [81].

Toadflax can also establish and spread in sparsely vegetated areas and sites with naturally-occurring disturbances, small openings, and/or little competition between species. Examples of such sites include dry, open areas in grassland and bunchgrass communities, sagebrush, open coniferous forests, sand dunes, riparian areas, and borders of woods (e.g. [2,11,16,56,57,61,67,77,81,82,107,113]).

Toadflax populations may establish but not spread widely into nearby natural areas. At a disturbed site in northern Manitoba, for example, yellow toadflax is among the 45% of introduced species that persist after initial establishment, as indicated by surveys done in 1959 and again in 1989. These yellow toadflax populations reproduce vegetatively, but do not mature fruits during the short growing season. Yellow toadflax is completely absent from natural communities in the area, and rarely occurs away from points of introduction. It does occur away from these points in the vicinity of human habitations or human disturbance (e.g. roadsides and railway tracks) [101]. This study site is near the northern limits of yellow toadflax's range (approximately 55° to 65° north latitude) [95].

Toadflax is most often found in well-drained, relatively coarse-textured soils varying from coarse gravels to sandy loams, but is sometimes found in heavier soils in North America. Similarly, native Eurasian habitats of this species are predominantly sandy, gravelly, or rocky [1]. Dalmatian toadflax is highly competitive in areas where summers tend to be dry in the northwestern and intermountain areas of the U.S., particularly on south- and southeast-facing slopes [2,57,88].

In central Europe, yellow toadflax prefers dry to moderately humid sandy loam soils that are moderate to rich in nutrients and minerals. Yellow toadflax may exhibit heavy metal tolerance. Yellow toadflax is more

commonly associated with relatively summer-moist, coarse soils in the northwestern and north-central U.S. Yellow toadflax may grow well in moist areas of high fertility, but is more likely to be displaced by other species than on drier, less fertile sites. Yellow toadflax plants growing on dry sites are stunted but tend to be comparatively more persistent [95]. In many areas in North America, yellow toadflax is infrequent except in areas disturbed by cultivation [56,95].

The following table provides some elevation ranges for Dalmatian toadflax by geographic area:

Area	Elevation	References
Colorado	up to 9,400 feet (2,900 m)	[67]
Intermountain area	5,200 to 8,200 feet (1,600-2,500 m)	[14]
Nevada	3,000 to 7,000 feet (900-2,100 m)	[48]
New Mexico	5,000 to 6,000 feet (1,500-1,800 m)	[62]
Utah	4,400 to 10,000 feet (1,300-3,100 m)	[119]
Wyoming (Yellowstone National Park)	<6,200 feet (<1,900 m)	[2]

The following table provides some elevation ranges for yellow toadflax by geographic area:

Area	Elevation	References
Intermountain area	6,600 to 9,200 feet (2,000-2,800 m)	[14]
Nevada	5,000 to 6,500 feet (1,500-2,000 m)	[48]
New Mexico	6,000 to 7,500 feet (1,800-2,300 m)	[62]
Utah	6,400 to 9,200 feet (1,950-2,800 m)	[119]

SUCCESSIONAL STATUS:
Toadflax can readily establish on open and disturbed sites where competition from other plants is reduced [11,57,95]. While individual crowns of toadflax are relatively short-lived (~4 years), individual patches may persist for more than 13 years on some sites. Soil disturbance and freedom from competition are important for stand persistence. On some sites, stands may disappear for several years and then reestablish from either buried seeds or vegetative buds [88,114].

Dalmatian toadflax is often associated with several other nonnative, invasive species. In ponderosa pine/Idaho fescue associations in northeastern Washington, grazing pressure can shift understory dominance from native grasses to cheatgrass, Dalmatian toadflax, and St. Johnswort (*Hypericum perforatum*), apparently irreversibly [16,25]. Dalmatian toadflax is competitive with cheatgrass in large parts of eastern Washington on the eastern edge of the Columbia Basin [38]. Dalmatian toadflax may be more tolerant of control methods, especially herbicides, than other species, and may therefore establish or spread following control attempts. In British Columbia, Dalmatian toadflax appears to be spreading as diffuse knapweed (*Centaurea diffusa*) and spotted knapweed are controlled [40]. Similarly, Dalmatian toadflax invaded sites where biological control has suppressed St. Johnswort on rangeland in Washington and Idaho [114].

Succession may also lead from toadflax dominance to dominance by other invasive species. Sites where Dalmatian toadflax has established in Washington, for example, may be susceptible to infestations by rush skeletonweed (*Chondrilla juncea*) [73].

While toadflax tends to be more common in open areas, Dalmatian toadflax also tolerates moderate amounts of shade. At Yellowstone National Park, Dalmatian toadflax was found under a wide range of canopy cover, from 0 to 85%, although it was predominantly found under low canopy cover [2].

SEASONAL DEVELOPMENT:
Toadflax phenology can be variable, as it is dependent on environmental conditions.

In early autumn, 1st-year Dalmatian toadflax plants often produce prostrate stems, forming a mat-like rosette that survives into the following spring. This "rosette stage" is important for carbohydrate storage. The following spring, floral stems grow from the prostrate stems. This sequence also occurs to a lesser degree in mature plants [88]. With the exception of these prostrate stems, top-growth dies back in the fall and is regenerated from the root system each spring [57].

Toadflax seedlings emerge both in spring and fall [87,95,114]. Dalmatian toadflax seedlings emerging in spring appear to have a higher survival rate than those emerging in fall [87,114]. In eastern Washington, Dalmatian toadflax emerges on south-facing slopes during the 1st or 2nd week in March through the 3rd week in April. Emergence on level ground occurs 2 to 3 weeks later, coinciding with soil temperatures of 50 degrees Fahrenheit (10 °C) at a depth of 1 inch (2.5 cm) [57,87]. Yellow toadflax seedling emergence begins in early to mid-May in Alberta [69], and earlier in warmer regions.

In northern Germany (also relevant to phenology in Canada), yellow toadflax vegetative shoots usually emerge in early to mid-April, when soil temperatures reach 42 to 50 degrees Fahrenheit (5-10 °C), and possibly in mid- to late March in warmer regions of the U.S. [57,95]. Dalmatian toadflax plants observed in eastern Washington fields developed floral stems only after a winter's dormancy and exposure to temperatures below 68 degrees Fahrenheit (20 °C). Floral stems emerge a few days later than seedlings in the spring [88]. Weak floral stems and some seed can be produced by 1st-year seedlings [87].

Flowering of Dalmatian toadflax begins in May or June and continues until August or October, but can occur earlier in warm seasons or warm habitats [11,57,87]. When flowering stems of yellow toadflax are 16 to 24 inches (40-60 cm) tall, branching begins, which signals the beginning of flower bud formation [57,95]. In northern Germany, yellow toadflax flower buds occur at the end of June, flowering begins mid-July, and the peak of flowering is at the end of July. On warm sites in Canada, flowering may begin in mid-June [95].

The following table provides some flowering dates for Dalmatian toadflax by geographic area:

Area	Flowering dates	References
Great Plains	July to August	[31]
Illinois	June to September	[66]
Intermountain area	July to August	[14]
New Mexico	May to September	[62]
northeastern U.S.	July, August	[28]

The following table provides some flowering dates for yellow toadflax by geographic area:

Area	Flowering dates	References
Blue Ridge (NC, SC, TN, VA)	June to September	[122]
Carolinas	June to August	[79]
Great Plains	June to August	[31]
Illinois	May to November	[66]
Intermountain area	June to August	[14]

Nevada	June to September	[48]
New Mexico	July to September	[62]
northeastern U.S.	May to September	[28]
north-central Texas	May	[19]
West Virginia	June to October	[104]

Dalmatian toadflax seed production begins in late June or early July and continues until September or early October in northern climates. Toadflax seed dispersal may begin on lower portions of the stem while flower buds are still forming on upper portions. Dalmatian toadflax seed dispersal begins as early as July in northern climates and continues into winter [88]. In a greenhouse study in Washington, most seeds were produced between late July and early September, and about 97% of seeds were produced in the first 5 weeks of production [87]. Yellow toadflax seed dispersal begins in August or September in northern climates and continues into winter [12,69,95]. In a study in Alberta, yellow toadflax capsules were formed and open by early August, when stem height was up to 3.3 feet (1 m), and seed shed started 2 weeks later. The majority of seed was shed between late September and October [69].

Yellow toadflax ramets die at freezing temperatures but the stronger stems, including some fruit capsules, may remain erect. Some seeds may remain in the fruit capsule until strong winds occur or until the stem falls over [95]. Dried floral stalks can remain standing for 2 years, retaining some seeds but dispersing most during the 1st year [88].

FIRE ECOLOGY

SPECIES: Linaria spp.

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations:

Toadflax has a deep and extensive perennial, sprouting root system that is likely to allow it to survive even severe fire. Toadflax is also capable of establishing either from on-site seed, or seed dispersed into a burned area. Seed may be dispersed by animals into recently burned areas where it is adapted to establish under conditions of reduced competition. It is unclear what the effects of fire are on toadflax seed.

Fire regimes:

Dalmatian toadflax occurs in ecosystems with historic fire regimes of varied frequency and severity; from frequent, low-severity fires in ponderosa pine ecosystems, to less frequent and more severe fires in bunchgrass and sagebrush ecosystems, to frequent and severe fires in plains and prairie grassland ecosystems. Yellow toadflax occurs primarily in agricultural communities in the western U.S. and throughout Canada, and in disturbed areas in the north-central and northeastern U.S. A variety of native plant communities once dominated these areas, and historic fire regimes have been dramatically altered.

Toadflax was not widespread in these communities when historic fire regimes were functioning, but has established since habitat alteration and fire exclusion began. It is unclear how historic fire regimes might affect toadflax populations, and it is unclear how the presence of toadflax in native ecosystems might affect fire regimes.

In general, in ecosystems where toadflax replaces plants similar to itself (in terms of fuel characteristics), it

may alter fire intensity or slightly modify an existing fire regime. However, if toadflax is qualitatively unique to the invaded ecosystem, it has the potential to completely alter the fire regime [15]. No examples of fire regimes altered by toadflax invasion are described in the available literature.

The following table provides fire return intervals for plant communities and ecosystems in which toadflax may be found. If you are interested in the fire regime of a plant community that is not listed here, please consult the complete FEIS list of fire regimes.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
bluestem prairie	*Andropogon gerardii* var. *gerardii-Schizachyrium scoparium*	< 10 [52,74]
Nebraska sandhills prairie	*A. g.* var. *paucipilus-S. s.*	< 10
bluestem-Sacahuista prairie	*Andropogon littoralis-Spartina spartinae*	< 10
sagebrush steppe	*Artemisia tridentata/Pseudoroegneria spicata*	20-70 [74]
plains grasslands	*Bouteloua* spp.	< 35 [74,123]
cheatgrass	*Bromus tectorum*	< 10 [75,121]
curlleaf mountain-mahogany*	*Cercocarpus ledifolius*	13-1,000 [5,96]
mountain-mahogany-Gambel oak scrub	*C. l.-Quercus gambelii*	< 35 to < 100
Arizona cypress	*Cupressus arizonica*	< 35 to 200 [74]
California steppe	*Festuca-Danthonia* spp.	< 35 [74,103]
juniper-oak savanna	*Juniperus ashei-Quercus virginiana*	< 35
western juniper	*J. occidentalis*	20-70
Rocky Mountain juniper	*J. scopulorum*	< 35
tamarack	*Larix laricina*	35-200 [74]
wheatgrass plains grasslands	*Pascopyrum smithii*	< 5-47+ [74,78,123]
pinyon-juniper	*Pinus-Juniperus* spp.	< 35 [74]
jack pine	*P. banksiana*	<35 to 200 [21]
Rocky Mountain lodgepole pine*	*P. contorta* var. *latifolia*	25-300+ [3,4,90]
Sierra lodgepole pine*	*P. c.* var. *murrayana*	35-200 [4]
Colorado pinyon	*P. edulis*	10-400+ [23,30,50,74]
Jeffrey pine	*P. jeffreyi*	5-30
western white pine*	*P. monticola*	50-200
Pacific ponderosa pine*	*P. ponderosa* var. *ponderosa*	1-47 [4]
interior ponderosa pine*	*P. p.* var. *scopulorum*	2-30 [4,7,59]
Arizona pine	*P. p.* var. *arizonica*	2-15 [7,13,98]
red pine (Great Lakes region)	*P. resinosa*	10-200 (10**) [21,26]
red-white-jack pine*	*P. r.-P. strobus-P. banksiana*	10-300 [21,41]
eastern cottonwood	*Populus deltoides*	< 35 to 200 [74]

aspen-birch	*P. tremuloides-Betula papyrifera*	35-200 [21,115]
quaking aspen (west of the Great Plains)	*P. tremuloides*	7-120 [4,34,64]
mountain grasslands	*Pseudoroegneria spicata*	3-40 (10**) [3,4]
California oakwoods	*Quercus* spp.	< 35 [4]
oak-hickory	*Q.-Carya* spp.	< 35 [115]
oak-juniper woodland (Southwest)	*Q.-Juniperus* spp.	< 35 to < 200 [74]
northeastern oak-pine	*Q.-Pinus* spp.	10 to < 35
white oak-black oak-northern red oak	*Q. alba-Q. velutina-Q. rubra*	< 35 [115]
canyon live oak	*Q. chrysolepis*	<35 to 200
blue oak-foothills pine	*Q. douglasii-P. sabiniana*	<35 [4]
northern pin oak	*Q. ellipsoidalis*	< 35 [115]
Oregon white oak	*Q. garryana*	< 35 [4]
California black oak	*Q. kelloggii*	5-30 [74]
bur oak	*Q. macrocarpa*	< 10 [115]
oak savanna	*Q. m./Andropogon gerardii-Schizachyrium scoparium*	2-14 [74,115]
black oak	*Q. velutina*	< 35 [115]
little bluestem-grama prairie	*S. scoparium-Bouteloua* spp.	< 35 [74]
elm-ash-cottonwood	*Ulmus-Fraxinus-Populus* spp.	< 35 to 200 [21,115]

*fire return interval varies widely; trends in variation are noted in the species summary
**mean

POSTFIRE REGENERATION STRATEGY [102]:
Geophyte, growing points deep in soil
Ground residual colonizer (on-site, initial community)
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Linaria spp.

IMMEDIATE FIRE EFFECT ON PLANT:
Toadflax is likely to be top killed by fire, however its deep, extensive root system is likely to survive even severe fire and allow reestablishment of the population from vegetative buds on roots. Many root-sprouting plants, including toadflax, have high fire survival rates, regardless of burn severity. This is because even the

most severe fires typically damage roots only to 4 inches (10 cm) below the soil [29], and toadflax roots typically penetrate the soil to a depth of several feet.

There is little information available regarding the direct effects of fire on toadflax plants, and no information available regarding heat or fire effects on toadflax seed.

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No additional information is available on this topic.

PLANT RESPONSE TO FIRE:
Toadflax is able to recover after fire and may even be promoted by fire, especially if other species are reduced. The postfire environment is well suited to toadflax establishment by seed.

Three sites in big sagebrush-bluebunch wheatgrass communities in western Montana were burned under prescription in mid-March to reduce shrubs and trees. Dalmatian toadflax density, cover, biomass per square meter, per plant biomass and per plant seed production were measured on burned plots and immediately adjacent unburned plots 6 months after burning. Dalmatian toadflax density and cover were not different between burned and unburned plots. Biomass of Dalmatian toadflax per square meter varied depending on site, while biomass per plant was significantly higher ($p>0.05$) on all burned plots compared with unburned plots. Burning also significantly increased ($p>0.05$) Dalmatian toadflax seed production per plant at all 3 sites. Seed production ranged from 7 to 79 seeds per plant on unburned plots, and from 158 to 1,328 seeds per plant on burned plots [44].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Response of toadflax to fire may depend on site characteristics and the fire adaptations of other species in the plant community. Most reviews suggest that toadflax is likely to increase or to be unaffected by fire (e.g. [11,57,95,114]). Several studies provide examples of toadflax establishment following fire [54,76,92,93,100].

A study in south-central New York designed to investigate the effects of accidental spring fires on the vegetation and soils of native plant communities found that yellow toadflax cover in quaking aspen groves was not significantly different ($p<0.05$) between burned and unburned stands. The authors suggested that toadflax is a neutral species with regard to fire [105].

Other studies suggest that toadflax is negatively affected by fire (e.g. [71]), although experimental evidence is lacking. Percent cover of yellow toadflax decreased 2 growing seasons after spring prescribed fire on 2 study sites in Buena Vista Marsh, Wisconsin. Percent cover was recorded as follows [36]:

Study site 1				Study site 2			
Burn		Control		Burn		Control	
prefire	postfire	prefire	postfire	prefire	postfire	prefire	postfire
15.0	8.3	17.3	19.5	35.7	16.0	19.0	18.5

FIRE MANAGEMENT CONSIDERATIONS:
Fire as a control agent:
Burning is not usually a recommended or effective control method for toadflax, because root buds and buried seeds are unaffected by fire, and burning may increase competitiveness of toadflax by removing desirable plants [11,57,81,95]. Removal of toadflax top-growth may even stimulate production of vegetative shoots [51,57]. Nonetheless, Nernberg [71] describes a mixed-grass prairie restoration program in Saskatchewan in which "appropriately timed" prescribed burning is used to control growth and eliminate seed production in yellow toadflax and other nonnative invasive species; although no specific details or results are provided.

Scorching of floral stalks using propane burners can help prevent toadflax seed production [57].

Prescribed fire can be used as a management tool on some sites in an effort to restore historic fire regimes and promote desirable species. The disturbance created by fire may, however, favor many invasive species. At the time of this writing, there are ongoing studies in western Montana designed to test the effects of prescribed fire combined with herbicide application to control Dalmatian toadflax and other invasive species [85]. Herbicides may prevent domination by invasive species after fire in the short term; however, they also affect nontarget forbs that can compete with invasive species [45].

On a big sagebrush-bluebunch wheatgrass site in western Montana, Jacobs and Sheley [45] tested the effects of prescribed burning with and without herbicide application on density, cover, and biomass of Dalmatian toadflax and native forbs as well as species richness, diversity, and evenness. Herbicides (picloram at 0.56 kg a.i./ha, and chlorsulfuron at 0.075 kg a.i./ha) were applied in October (prior to burning) and April (after burning). Burning was conducted in April. They found that fire effectively killed nearly all trees on the test plots (primary objective of prescribed burning), but did not affect species richness, diversity, or evenness. One season after burning, the biomass and cover of toadflax, but not its density, were 2 times greater on burned plots than on unburned plots. All herbicide treatments reduced biomass, cover, and density of Dalmatian toadflax to 90% of the control. Chlorsulfuron decreased overall forb biomass to 50% of the control, while picloram decreased forb biomass to nearly 0. Both herbicides reduced richness and diversity, but not evenness. Timing of herbicide application made no difference in toadflax control or diversity indices, although spring application resulted in higher grass production. The authors conclude that using an herbicide such as chlorsulfuron may provide short-term control of Dalmatian toadflax. However, the combination of open niches left by forbs killed by herbicides, trees and shrubs killed by fire, and pressure on grasses by wildlife leaves sites susceptible to reestablishment of Dalmatian toadflax from the soil seed bank [45].

Postfire colonization potential:
Because of its propensity to establish in dry, open areas with little plant competition, toadflax has high potential for establishing after fire (when competition from other vegetation is removed or reduced) either by seed imported to the site or by soil-stored seed. Several examples follow where toadflax established following fire. It is not clear in any of these examples whether toadflax plants or seeds were on-site prior to burning.

Two fire case studies near Flagstaff, Arizona, (Chimney Spring and Limestone Flat) were established to determine a burning interval that would adequately manipulate fuels and stocking of a ponderosa pine stand so that it could survive wildfire. The initial objective was to reduce fuel loads by reintroducing fire in areas where it had long been suppressed and fuels had accumulated. The fire at Chimney Spring reduced forest floor fuels by 63%, compared to a 42% reduction of forest floor fuel at Limestone Flat. In both places, several invasive species were abundant after fire, including Dalmatian toadflax, common mullein (*Verbascum thapsus*), and thistle (*Cirsium pulchellum*). Common mullein and Dalmatian toadflax were dominant on heavily burned sites around large, old-growth trees that have died since the initial burns [92,93]. Similarly, Kyle [54] observed several sites in northern Arizona where large-scale, high-severity fires have burned over the past 4 decades and noted that many of these areas are dominated by nonnative plants such as cheatgrass, smooth brome (*Bromus inermis*), sweetclover (*Melilotus* spp.), orchardgrass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), and Dalmatian toadflax.

In ponderosa pine forest sites in northern Arizona in 1989, prescribed burning was conducted to investigate its effects on the rare plant, Flagstaff pennyroyal (*Hedeoma diffusum*). Dalmatian toadflax was not noted prior to burning or during counts from 1989 to 1995; but in 2000 it had invaded all of the spring burn plots, the control plot (which was adjacent to the spring burn plots), and none of the fall burn plots. It is unclear whether it was present prior to the initiation of the study, or if it was introduced during fire line construction, or following burning; however, it had not yet invaded the area surrounding the burn study area where grasses were very dense. The authors urge caution and awareness of Dalmatian toadflax and other weed species when prescribing fire treatments [76].

Yellow toadflax was found in a jack pine-lichen woodland of the upper boreal forest in northern Quebec, 2 years after wildfire [100].

Toadflax invasion after fire may also be related to soil disturbances brought about through fire suppression activities. For example, after a wildfire and suppression activities in Glacier National Park, Montana, Dalmatian toadflax was found in trace amounts in bulldozed areas, but was not present in either burned or undisturbed areas [8].

Preventing postfire establishment and spread:
The USDA Forest Service's "Guide to Noxious Weed Prevention Practices" [109] provides several fire management considerations for preventing establishment of invasive species that apply to toadflax.

Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This can be accomplished through early detection and eradication by careful monitoring, and by limiting invasive plant seed dispersal into the burned area by [29,109]:

- re-establishing vegetation on bare ground as soon as possible
- using only certified invasive plant-free seed mixes when revegetation is necessary
- cleaning equipment and vehicles prior to entering the burned area
- regulating or preventing human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- detecting weeds early and eradicating before vegetative spread and/or seed dispersal
- eradicating small patches and containing or controlling large infestations within or adjacent to the burned area

Early detection is key, and monitoring in spring, summer, and fall is imperative. Eradicate newly established toadflax plants and small patches adjacent to burned areas to prevent or limit seed dispersal into the site [29,109]

Revegetation necessity can be based on the degree of desirable vegetation displaced by invasive plants prior to burning and on postfire survival of desirable vegetation. Revegetation necessity can also be related to invasive plant survival as viable seeds, root crowns, or rhizomes capable of reproduction. In general, postfire revegetation should be considered when desirable vegetation cover is less than about 30% [29].

When prefire cover of toadflax is absent to low (and has been so for 10 or more years- i.e. no seeds in the seed bank), and prefire cover of desirable vegetation is high, revegetation is probably not necessary after low- and medium-severity burns. After a high-severity burn on a site in this condition, revegetation may be necessary (depending on postfire survival of desirable species), and intensive monitoring for invasive plant establishment is necessary to detect and eradicate newly established invasives before they spread [29].

When prefire cover of toadflax is moderate (20 to 79%) to high (80-100%), revegetation may be necessary after fire of any severity if desired vegetation cover is less than about 30%. Toadflax plants are likely to survive even severe fires, so intense weed management is also recommended, especially after fires of moderate to high severity [29].

Fall dormant broadcast seeding into ash will cover and retain seeds. If there is insufficient ash, seedbed preparation may be necessary. A seed mix should contain quick-establishing grasses and forbs (exclude forbs if broadleaf herbicides are anticipated) that can effectively occupy available niches. Managers can enhance the success of revegetation (natural or artificial) by excluding livestock until vegetation is well established (at least 2 growing seasons) [29].

When planning a prescribed burn, managers should preinventory the project area and evaluate cover and

phenology of any toadflax present on or adjacent to the site, and avoid ignition and burning in areas at high risk for toadflax establishment or spread due to fire effects. Avoid creating soil conditions that promote weed germination and establishment. Discuss weed status and risks in burn rehabilitation plans. Also, wildfire managers might consider including weed prevention education and providing weed identification aids during fire training; avoiding known weed infestations when locating fire lines; monitoring camps, staging areas, helibases, etc., to be sure they are kept weed free; taking care that equipment is weed free; incorporating weed prevention into fire rehabilitation plans; and acquiring restoration funding. Additional guidelines and specific recommendations and requirements are available [109].

MANAGEMENT CONSIDERATIONS

SPECIES: Linaria spp.

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Very little information is available regarding the use of toadflax by livestock and wildlife. A review by Lajeunesse [57] notes that Dalmatian toadflax and yellow toadflax evolved in plant communities that are grazed moderately to intensely, primarily by domestic sheep and goats and to a lesser extent by cattle. Cattle will sometimes casually browse flowering shoots, while domestic sheep will use Dalmatian toadflax as a major food source [57]. Domestic sheep and goats have been used to control toadflax [57,106].

A review by Saner and others [95] points out that several secondary compounds present in yellow toadflax may explain why cattle avoid it. It contains glycosides that may be insecticidally active, flowers contain flavonoids, and seeds contain saponins. This review also indicates that cattle eat dried yellow toadflax, that yellow toadflax is not generally poisonous to livestock, and that it has been used as a medicinal plant for cattle that cannot ruminate [95]. According to Mitich [65], occasional cases of mild poisoning from yellow toadflax have been reported for cattle, but such cases are rare because cattle usually avoid toadflax.

Uresk and Lowrey [112] found no evidence through fecal analysis that cattle consumed yellow toadflax in an area where it was abundant. Estimates of toadflax use by cattle may be inaccurate if identified by microhistological analysis, since the toadflax epidermis apparently does not survive the slide making process [94].

Although deer have been observed to graze Dalmatian toadflax, and toadflax seed is used by some species of birds and rodents, it is not known to be heavily used by any native animal species [87].

Palatability/nutritional value:
Toadflax is usually avoided by cattle as it is said to be distasteful, or mildly poisonous [57,65].

Cover value: Toadflax can provide cover for small animals [57].

OTHER USES:
Yellow toadflax is used in folk medicine and homeopathy; as an insecticide; as a yellow dye; and as a plant of religious and magical attributes [65,95].

Yellow toadflax is said to be useful to prevent erosion, and in reclamation of mined areas, sites despoiled by dumping of heavy metal-laden sewage sludge, and abandoned gravel pit slopes [95].

IMPACTS AND CONTROL:

Impacts:

Toadflax can be a serious agricultural weed that is favored by reduced-tillage farming methods, is resistant to many herbicides, and provides over-wintering sites for cucumber mosaic virus and broad bean wilt virus in New York [95].

Its impacts in wildlands and natural areas are not as clear. Like any invasive plant, it can displace plant communities and associated animal life. This can result in a loss of forage in pastures and rangelands that can impact livestock and some big game species, especially on winter ranges. Where sod-forming or bunchgrass communities are replaced by toadflax, soil erosion, surface runoff, and sediment yield can be increased. However, on harsh, sparsely vegetated sites toadflax can actually help stabilize soil [57,95].

In a survey of ranchers and farmers in north-central Idaho, 1% of respondents perceived Dalmatian toadflax as a moderate threat in 1982, and none perceived it as a problem in 1988 [10]. Toadflax can, however, spread rapidly, and it is important to eradicate infestations while they are still small in order to contain their spread [24,120]. For example, Dalmatian toadflax was introduced at a mine site in the 1970s on private land adjacent to the Raymond Mountain Wilderness Study Area in Wyoming. From this site, Dalmatian toadflax spread over 15 years to cover a 10-mile radius in the wilderness area and adjacent private land [120].

Control:

Keys to successful control of toadflax are prevention of seed production, depleting root reserves, and killing seedlings before vegetative reproduction begins (within 2-3 weeks of germination) [11,95]. Reducing seed production may limit the spread of toadflax, although is not likely to result in a reduction of toadflax stand size or density because of vigorous vegetative reproduction. Reduction of toadflax stand size or density is more likely achieved by reducing the number of stems, limiting toadflax stem and lateral root-bud production, and encouraging desirable plant populations that provide strong competition for resources [32].

The diverse geographic range of toadflax throughout North America and its genetic variability result in localized populations that can respond differently to the same management methods and environmental conditions. Determining the most effective and economical control methods for a particular toadflax population will require annual monitoring, mapping, evaluation, and follow-up treatments. In this way, site-specific management efforts can be adjusted to determine the best combination of control strategies for a particular site [57].

Monitoring treatment areas is best done when toadflax plants have formed buds and are beginning to flower (around early June in most areas). Many control techniques are most effective at this time because root carbohydrate reserves are at their lowest, which makes it more difficult for root systems to recover. Follow-up work within the first 2 months of initial treatment (in late June or early July) is recommended to locate and remove any late-flowering plants [11].

Because toadflax occurs and is competitive with several other invasive species (e.g. [16,25,38,40]), management to control it and/or other species must consider the possibility of succession to an equally undesirable species when plants are removed [38,40,58,73,114].

Prevention:

Because toadflax species are expensive, labor-intensive, and difficult to manage once established, preventing infestations is the most time- and cost-effective management approach. This is accomplished by maintaining desirable plant communities, by preventing toadflax seeds and root pieces from entering uninfested areas, and by careful monitoring for and early eradication of newly established plants. This is especially important where toadflax is common in areas around the management site, especially along roads, trails, and rivers (e.g. [81]).

Maintain desirable plant communities by limiting spring grazing (since toadflax seedlings can more effectively

compete with grazed plants), minimizing soil disturbance, and seeding disturbed sites with desirable species (see Fire Management Considerations and Cultural control) [57,81,95].

Prevent seeds and root pieces from entering uninfested areas as follows [57]:

- Check and clean equipment before moving it into uninfested areas or before bringing it from infested areas
- When moving livestock from infested to uninfested areas, hold them in corrals or small pastures until viable seeds have had time to pass through the digestive tract (6 days for cattle, 11 days for sheep)
- Monitor for toadflax seedling establishment in livestock holding areas and areas where fill dirt has been imported
- Avoid purchasing feed or seed that could be contaminated with weed seeds

Toadflax is a common roadside weed. Prevention of its establishment (and the establishment of many other invasive species) requires that road construction projects be avoided whenever possible, especially in nature reserves. When unavoidable, road construction projects should be treated and funded as 10- to 20-year biological projects rather than 1- to 2-year engineering projects, with biologists and resource managers overseeing road construction. Projects should not be considered complete until native vegetation is fully established. Topsoil removed during construction can be redeposited in roadside ditches, and roadsides reseeded with native species. Roadsides should then be regularly monitored and actively managed for control and eradication of nonnative species [107].

Integrated management:

Successful management of toadflax requires integrating as many management strategies as possible. Management programs for toadflax should emphasize both the prevention of seed formation and vegetative spread [57].

Physical/mechanical:

Removal of the aboveground portion of toadflax plants can eliminate seed production for that year (if done in spring or early summer, before seed set), and reduce the current year's growth, but it will not kill them. Removal each year for 5 or 6 years may be necessary to deplete the remaining root system of reserves, and 10 to 15 years may be required to remove seedlings produced from dormant seeds. Hand-pulling, mowing, and tillage can be effective in preventing seed production and starving toadflax roots, thereby controlling infestations under certain conditions only if done repeatedly and/or in combination with other control methods [11,57,95].

Pulling toadflax by hand can effectively remove seedlings and small infestations and limit spread of large infestations by pulling around patch perimeters. Pulling is most effective in sandy or moist soils, because more root length can be removed. It is important to pull as much of the root as possible and to follow lateral roots to their ends [11,57]. Managers at several nature preserves in Colorado, Idaho, and Oregon have used hand-pulling to remove toadflax and keep infestations from spreading. Most say that early treatment, removal of as much of the roots as possible, and persistence for several years are important for hand-pulling to be effective [51,81,82]

A decade-long hand-pulling experiment at Magnusson Butte Preserve, Washington, demonstrates the effectiveness of repeated hand-pulling. The experiment was begun in a 5 by 5 meter test plot, and was then expanded to the entire 28-acre preserve. During the 1st week of June, a team of about 30 volunteers walked the preserve pulling all toadflax plants found. At this time, flowers were beginning to appear making plants easier to locate, and soils were still moist, making plants easier to pull with minimal soil disturbance. In the beginning, stems were removed in bags to avoid a mulching effect on desirable native plants, but in later years

when there were fewer plants they were dropped in place with no ill effect. A follow-up visit was conducted during the last week in June to remove any late-flowering plants that might have been missed. Teams were able to reduce the number of flowering stems each year by an estimated 90-95% preserve-wide. In the 3rd year, it was noticed that flowering stems were not only reduced in number, but were smaller in size and lower in vigor [11].

Mowing and cutting of toadflax may be used to help decrease seed production, but will not eliminate toadflax stands [81,95,114]. Cutting flowering stems every year for several successive years can stress plants and help control infestations [51]. Mowing and cutting are usually not recommended, because they do not prevent root growth or affect buried seed [57]. Cutting may even contribute to stand longevity by stimulating dormant buds in the axils of vestigial leaves at the bases of cut floral shoots, as was observed in Dalmatian toadflax in Washington [88,89]. Considerable secondary and tertiary branching can occur following injury to the main stem [1]. Mowing may be less effective than cutting since plants that are cut several inches above the soil surface may sprout more rapidly. In addition, mowing may seriously damage desirable plants and is usually not feasible or desirable in natural areas [11].

Consistent, intensive, clean cultivation for at least 2 years with 8 to 10 cultivations the 1st year and 4 to 5 cultivations the 2nd year, will control toadflax (reviews by [95,114]). Care must be taken not to transport toadflax root pieces to clean fields, as root pieces as short as 1 cm long can sprout new plants and expand rapidly [68]. Seedlings less than 2-3 weeks old are particularly susceptible to tillage since, at this stage, vegetative reproduction has not started [95]. Tillage is generally inappropriate for natural areas.

Fire: See Fire Management Considerations.

Biological: Tu and others [106] provide information and considerations for biological control of invasive species in general in their Weed Control Methods Handbook. Carpenter and Murray [11] provide detailed information on biological control of toadflax, including contacts for authorities on each of the insects used. These documents can be accessed through The Nature Conservancy's Wildland Invasive Species Program website.

Several insect species that feed on toadflax have been purposely or accidentally released in the U.S. and Canada. Flower feeding beetles (*Brachypterolus pulicarius* and *Gymnetron antirrhini*) appear to be the most important insects for reducing seed production in toadflax. *B. pulicarius* larvae develop inside floral ovaries, and adults feed on buds and young stems. *B. pulicarius* can reduce seed production in yellow toadflax by 80 to 90%, and by 43 to 93% in Dalmatian toadflax [33]. *G. antirrhini* can reduce seed production in yellow toadflax by 85-90% [72]. A stem-boring weevil (*Mecinus janthinus*), whose larvae and adults feed on shoots of both toadflax species, seems to be the most promising biocontrol agent for toadflax as of this writing [37,108]. Of the biocontrol agents listed for toadflax, the toadflax moth (*Calophasia lunula*) is not suggested for redistribution since it attacks native snapdragons in California [108].

The following table provides information on some insects tested and/or released for control of toadflax:

Agent	Plant attacked	Status	States established	References
toadflax flower-feeding beetle (*Brachypterolus pulicarius*)	mainly yellow toadflax with a "strain" that feeds on Dalmatian toadflax	yellow toadflax strain accidentally introduced; Dalmatian toadflax strain collected and released in Montana	well established in most yellow toadflax infestations in North America	[17,33,63,72,95]

toadflax moth (*Calophasia lunula*)	primarily yellow toadflax	deliberately tested and released in 7 states; most releases failed to establish; larvae feed on new vegetative shoots and terminal portions of stems	ID,MT,WA	[17,72,95]
root-boring moth (*Eteobaliea serratella*)	Dalmatian toadflax and yellow toadflax	approved for release in 1995; no established populations confirmed	---	[72,95]
root-boring moth (*E. intermediella*)	Dalmatian toadflax and yellow toadflax	approved for release in 1995; no established populations confirmed	---	[72,95]
toadflax capsule weevil (*Gymnetron antirrhini*)	mainly yellow toadflax with a "strain" that feeds on Dalmatian toadflax	accidentally introduced	widespread and common at yellow toadflax sites; eastern Canada, BC; ID, MT, OR, WA, WY	[17,72,95]
weevil (*G. netum*)	mainly yellow toadflax with a "strain" that feeds on Dalmatian toadflax	accidentally introduced; larvae develop inside fruit and adults feed on buds, leaves, and stems	established on yellow toadflax several states in northern U.S. and in BC	[17,95]
stem-boring weevil (*Mecinus janthinus*)	Dalmatian toadflax and yellow toadflax	field releases have been made at several sites in western U.S. and Canada	established in BC, AB and WA; small populations established in CO, ID, MT, OR, SD, UT, WY	[37,72,95]

Domestic sheep and goats have been used to control toadflax [57,106]. Preliminary results of field trials in Montana show that domestic sheep can help suppress stands of Dalmatian toadflax and limit seed production. In these studies, 1,000 ewes and lambs were placed in a hilly rangeland area of moderate to heavy infestations of Dalmatian toadflax (densities of 25 to 100% of the vegetation). Approximately 35 to 45% of toadflax foliage was stripped, including the terminal 6 to 10 inches (15-25 cm) of plant stems. Although domestic sheep only nibbled the plants initially, within 2 to 3 weeks they were consuming Dalmatian toadflax regularly, even though other forage was present. In these studies, the sheep did well and showed acceptable weight gain ([57] and references therein).

Chemical: Tu and others [106] provide information and considerations for chemical control of invasive species in general, and detailed information on individual chemicals and adjuvants in their Weed Control Methods Handbook. Carpenter and Murray [11] provide detailed information on chemical control of toadflax, including contacts for authorities on each of the chemicals discussed. These documents can be accessed

through The Nature Conservancy's Wildland Invasive Species Program website.

Lajeunesse [57] suggests that chemical control of toadflax is complicated by the plant's high genetic variability, the waxy leaf surface that can hinder herbicide uptake, and coarse soils (in which toadflax is often found) that can allow herbicides to leach below the root zone. Even when chemical control appears effective, reinvasion by toadflax may occur from buried seed. Where herbicides appear effective, it is necessary to treat an infestation every 3 to 4 years for as long as 12 years [57]. Permanent, long-term control of toadflax cannot be achieved with herbicide treatment alone ([95] and references therein).

Triclopyr, fluroxypyr, 2,4-D, MCPA, 2,4-DB, MCPB, and mecoprop are ineffective for toadflax control ([57,95] and references therein). Glyphosate did not effectively control toadflax, but did kill neighboring plants, thereby giving toadflax the competitive advantage [81]. Effective herbicides for Dalmatian toadflax include chlorsulfuron (results for 1-2 years) [45], dicamba (results for 1 year), picloram (although it is ineffective on some sites), and imazapic ([46,57,81] and references therein).

Picloram at the rate of 1.5 to 2 lb a.i. per acre, is purported to be the most effective herbicide treatment for Dalmatian toadflax in Montana, although it will not usually provide complete control [55], and it may also harm desirable plants.

Sebastian and Beck [97] measured percent control of Dalmatian toadflax and percent injury to crested wheatgrass (*Agropyron cristatum*) in plots treated with various rates of picloram, fluorxypyr, and a mix of the 2 chemicals applied at different time/growth stages for 3 years after application. Better control was achieved with lower rates of picloram (0.5 lb a.i./acre), possibly because there was less injury to competing wheatgrass at the lower rates. Fluroxypyr resulted in no control when applied alone, and did not improve control rates when mixed with picloram over picloram alone [97].

The reduction of desirable nontarget species by picloram may be unacceptably high at application rates recommended for toadflax control. At much lower rates (0.28 kg a.i./ha), fall applications of picloram depressed species richness and diversity on rough fescue grassland (*Festuca* spp.) and early seral Douglas-fir/snowberry forest (*Pseudotsuga menziesii*/*Symphoricarpos albus*) treated to control spotted knapweed in western Montana. In these cases species diversity recovered to untreated levels within 3 years of the initial applications, and the authors described these effects as "small and transitory." Spring applications, however, caused depressions in diversity that persisted through the last year of sampling (6 years after initial application) [84]. Similarly, applications of picloram at 0.56 kg a.i./ha (in combination with prescribed burning) to control Dalmatian toadflax on big sagebrush-bluebunch wheatgrass sites in southwestern Montana reduced biomass, cover, and density of Dalmatian toadflax to 90% of the control, and decreased overall forb biomass to nearly 100% of the control. Applications of chlorsulfuron had similar effects on Dalmatian toadflax in this study, but slightly less negative impact on native forbs. The authors conclude that while herbicides may help provide short-term control on burned rangeland, the combination of forb reduction, open niches from burned trees and shrubs, and pressure on grass from wildlife may leave sites susceptible to reestablishment of toadflax from the soil seed bank [45].

An experiment to determine the effects of 6 different herbicides at 3 rates on established spotted knapweed populations indicated that all rates reduced spotted knapweed biomass by 95-100%. However, suppression of spotted knapweed with clopyralid allowed yellow toadflax to become the dominant plant in those treatment areas. Picloram appeared to suppress yellow toadflax to some degree, as it did not become dominant in picloram treated plots [58]. Similarly, it appears that some agricultural herbicides encourage Dalmatian toadflax in Washington [81].

Cultural:

Vigorous, healthy plant communities can often outcompete toadflax seedlings and thus prevent their establishment. In areas where toadflax is already established, initial toadflax control should be followed by establishment of well-adapted, desirable plant species that provide competition throughout the season at all

levels of the soil-root profile. This can provide longer-term suppression. Proper grazing management to maintain the competitive ability of these plant communities is important for long-term control of toadflax [57,68].

Communities that are in good condition may recover without replanting desirable species as long as follow-up control is conducted annually. Increases in native and nonnative annual grasses, forbs, and residual native perennial forbs were observed following toadflax removal at Magnusson Butte Preserve in Washington. However, replanting native grasses and forbs can help accelerate recovery of an area [11].

Rose and others [91] tested 5 grasses ('Hycrest' crested wheatgrass (*Agropyron cristatum*), 'Luna' pubescent wheatgrass (intermediate wheatgrass (*Thinopyrum intermedium*)), 'Critana' thickspike wheatgrass (*Elymus lanceolatus*), 'Bozoisky' Russian wildrye (*Psathyrostachys juncea*), and 'Sodar' streambank wheatgrass (*Elymus lanceolatus*)) for their competitive ability against Dalmatian toadflax. They began by spraying the area (a dry, disturbed grassland site invaded by Dalmatian toadflax) with picloram in the fall, then rototilled and seeded the following April and August. Areas seeded in the spring to crested wheatgrass, intermediate wheatgrass, and thickspike wheatgrass showed significant ($p<0.05$) reductions of Dalmatian toadflax. The August seeding did not establish as quickly as the April seeding, but by the 3rd year, late summer seedings were all equal to or greater in competition than those established in spring. Dalmatian toadflax production (above ground dry weight) was greater in control plots than in plots seeded with thickspike, pubescent (intermediate), and crested wheatgrasses. Production of Dalmatian toadflax in areas seeded with streambank wheatgrass and Russian wildrye did not differ from production in unseeded controls. Each grass has characteristics that make it desirable in different situations, and areas to be revegetated should be assessed to determine which grasses would be most suitable depending on soil types, moisture level and use. Russian wildrye, intermediate wheatgrass, and crested wheatgrass are all nonnative species [91] and some of these are invasive in natural areas.

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